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## SEMI-EMPIRICAL CALIBRATION OF THE INTEGRAL EQUATION MODEL FOR CO-POLARIZED L-BAND BACKSCATTERING

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### ABSTRACT

The objective of this paper is to extend the semi-empirical calibration of the backscattering Integral Equation Model (IEM) initially proposed for SAR data at C- and X-bands to SAR data at L band. A large dataset of radar signal and in situ measurements (soil moisture and surface roughness) over bare soil surfaces were used.

A semi-empirical calibration of the IEM was performed at L band in replacing the correlation length derived from field experiments by a fitting parameter. Better agreement was observed between the backscattering coefficient provided by the SAR and that simulated by the calibrated version of the IEM.

**Index Terms**—Integral Equation Model, Synthetic Aperture Radar, L-band, Bare soil.

### 1. INTRODUCTION

The Integral Equation Model (IEM) ([1]) is widely used in inversion procedures of Synthetic Aperture Radar (SAR) images for retrieving soil moisture content and roughness. It simulates the radar backscattering coefficient for bare soils given sensor parameters (radar wavelength, incidence angle, and polarization) and soil characteristics (dielectric constant, standard deviation of heights, autocorrelation length, and autocorrelation function "ACF"). Most studies reported discrepancies between modeled

backscatters by IEM and observed backscatters by SAR sensors ([2]-[10]). These discrepancies were mainly related to the uncertainty on autocorrelation length measurements and on IEM itself.

Baghdadi et al. ([2]-[6]) proposed a semi-empirical calibration of the IEM in C- and X-bands, based on experimental data of SAR images and ground measurements (soil moisture content and roughness). The calibration consisted of finding a fitting parameter which replaces the autocorrelation length measurement so that the IEM reproduces better the radar backscattering coefficient ( $\sigma^0$ ). Calibration results showed that the fitting parameter was found dependent on rms surface height, radar wavelength, polarization, and incidence angle. Given the successful application in C- and X-bands, this paper aims at deriving similar equations for L-band.

### 2. DATABASE DESCRIPTION

Important experimental database of SAR images and measurements of soil moisture content and roughness acquired over bare soils were used. This database was collected over numerous agricultural study sites in France (2 sites), Luxembourg (1 site), Belgium (2 sites), Germany (1 site), and Italy (2 sites).

SAR images were acquired by various sensors (AIRSAR, SIR-C, JERS-1, PALSAR-1, ESAR) operating in L-band (~1.25 to 1.30 GHz), with incidence angles between 21.5° and 57°, and in HH and VV polarizations. In addition, in situ ground

measurements of soil moisture content (mv) and roughness were carried out for each experimental plot. The soil moisture measurements were collected from the top 5 or 10 cm of each experimental plot. Roughness measurements are made using laser or needle profilometers with several profiles for each experimental plot. From these roughness measurements, the root mean square (rms) surface height and the autocorrelation length (L) are calculated using the mean of all ACFs (one ACF by roughness profile). Soil moisture, rms surface height, and autocorrelation length range respectively from 3.5 to 40.9 vol %, 0.65 cm to 9.55 cm, and from 2.37 cm to 38.50 cm. A total of 141 experimental data points is available in HH and 73 in VV polarization.

### 3. EVALUATION OF THE IEM

IEM simulation results were slightly better with the exponential ACF than with the Gaussian ACF. Similarly, HH provides slightly better results than VV. With the exponential ACF, the mean difference between experimental data and IEM simulations is of +0.4 dB in HH and of -1.2 dB in VV with an RMSE about 3.3 dB. The use of Gaussian ACF causes higher biases in comparison to the exponential ACF (-1.2 dB in HH and -2.5 dB in VV), and RMSE of the same order of magnitude in HH (3.5 dB) but higher in VV (4.4 dB).

### 4. SEMI EMPIRICAL CALIBRATION OF THE IEM

In Baghdadi et al. ([2],[6]), the semi empirical calibration of the IEM consisted in the replacement of the experimental autocorrelation length by a fitting parameter (*Lopt*) in order to ensure better matching between simulations and SAR data (for C- and X-bands). The calibration parameter was found to be dependent on surface roughness, incidence angle, polarization, and radar wavelength.

The objective is to extend the same approach to L-band in order to improve the SAR backscatter prediction. The database was randomly divided into 90% training and 10% validation data elements. The prediction error on the radar backscattering coefficients based on a 10-fold cross-validation was estimated for each polarization in order to validate the predictive performance of the calibrated version of the IEM.

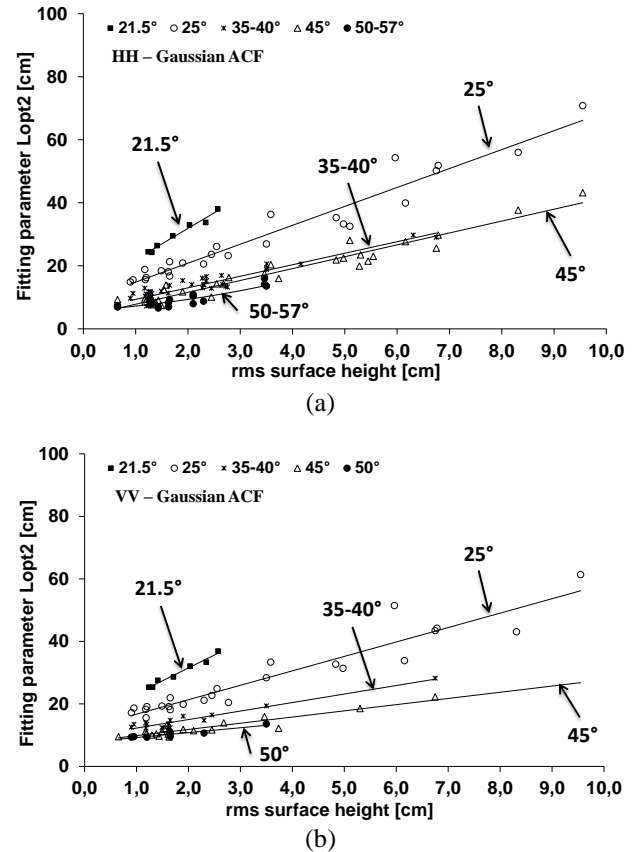
*Lopt* has two possible solutions, *Lopt1* (the lowest value) and *Lopt2* (the highest value). The sets of *Lopt1* and *Lopt2* data were then used to fit the best regressions between *Lopt* and rms height as a function of incidence angle and polarization. When *Lopt1* for either ACFs or *Lopt2* for the exponential ACF were used, the IEM had difficulties to ensure the correct physical behavior between  $\sigma^\circ$  and the rms surface height for low incidence angles (increasing  $\sigma^\circ$  with increasing rms, for a given moisture value). Only *Lopt2* with Gaussian ACF ensures a correct modeling of the physical behavior of  $\sigma^\circ$  with a linear relationship between *Lopt2* and rms:

$$Lopt2(rms, \theta, HH) = 2.6590 \theta^{-1.4493} + 3.0484 rms \theta^{-0.8044} \quad (1)$$

$$Lopt2(rms, \theta, VV) = 5.8735 \theta^{-1.0814} + 1.3015 rms \theta^{-1.4498} \quad (2)$$

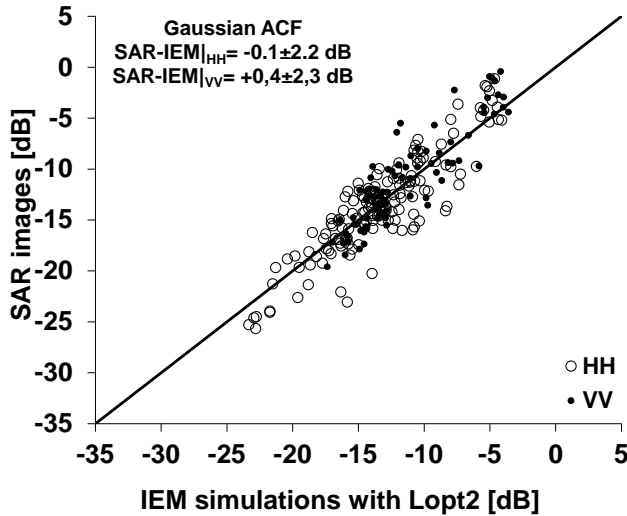
$\theta$  is in radian, *Lopt2* and rms are in cm.

Results showed that the fitting parameter *Lopt2* is strongly dependent on rms surface height and the incidence angle (Figure 1). It increases as the rms increases and decreases with the incidence angle.



**Figure 1:** Fitting parameter *Lopt2* as a function rms surface height with the Gaussian ACF.

Finally, to validate the generalization performance of  $Lopt2$  (equations 1 and 2), a 10-fold cross validation was used. Results showed that the proposed semi-empirical calibration of the IEM provides improved results. The biases and the standard deviations of the error have decreased for both HH and VV polarizations. The standard deviations of the error decreased from 3.2 dB to 2.2 dB for HH and from 3.5 dB to 2.3 dB for VV (Figure 2).



**Figure 2:** Validation of the semi-empirical calibration approach in using the fitting parameter  $Lopt2$ .

## 6. CONCLUSIONS

A semi-empirical calibration of the IEM was proposed using L-band SAR data with incidence angles between  $21.5^\circ$  and  $57^\circ$ . Similarly to results obtained in C- and X-bands, the dependence of the fitting parameter on *rms* surface height, incidence angle, polarization, and radar wavelength is found for L-band. With this calibration, bare agricultural soils can be characterized by two surface parameters (*rms* height and soil moisture) instead of four (*rms* height, autocorrelation length, autocorrelation function, and soil moisture) since the soil autocorrelation length is replaced by a fitting parameter defined for a Gaussian ACF. Results showed that this calibration ensures better agreement between IEM and the SAR data and increases the model's applicability.

## 7. ACKNOWLEDGEMENTS

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